Glaciers’ Response in a Warming Climate

Sebastian H. Mernild, CCS-2

The latest decade (2001–2010) was the warmest of the instrumental record, and more so at high latitudes—it is likely that this decade has been warmer than any other decade within the last thousand years. In the Arctic, for example, most observed glaciers and ice caps (GIC) shrank in area, indicating that glaciers and ice caps have lost an arithmetic average of one-fifth of their area since the mid-1980s. Overall, this shrinking area follows the observed mean global glacier and ice cap mass trend towards negative balances; however, the mass balance from the most recent pentad (2006–2010) shows more moderate, although still large, losses.

Glaciers and ice caps (this includes all glaciers except the Greenland Ice Sheet and the Antarctic Ice Sheet) are tracers of climate changes because air temperature and snowfall control their surface mass balance [1,2]. At high northern latitudes, the temperature rise of recent years has been more pronounced than the global average and around twice the global average for the past 100 years [3]. For example for Greenland, based on long-term temperature observations, the last decade was not only the warmest since 1890 but it also had the highest number of extreme warm years, higher by around 50% than the number in the warm 1930s and 1940s [4].

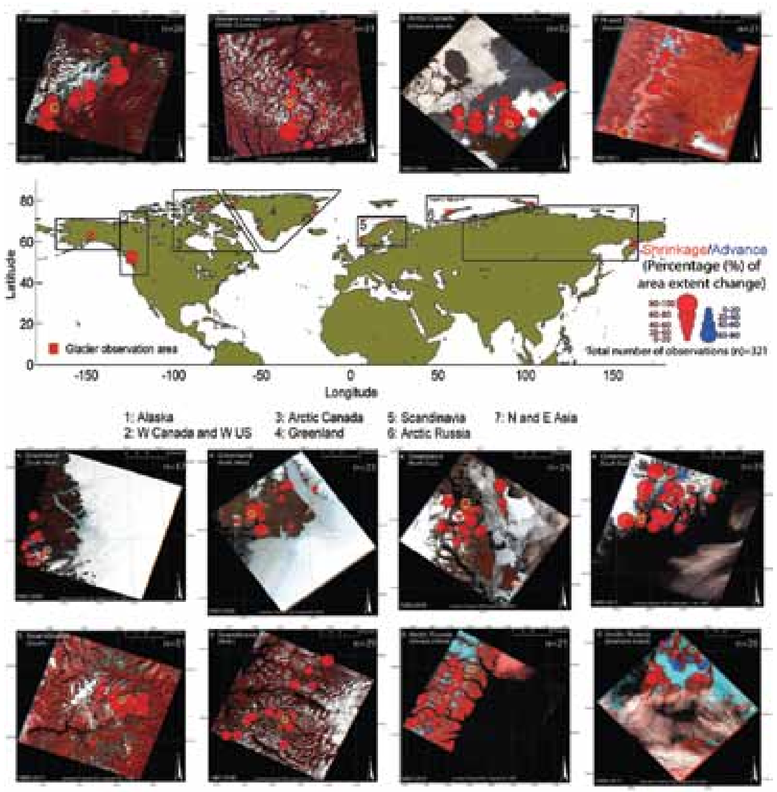

Fig. 1. Satellite-derived area changes of 321 glaciers and ice caps in the Pan-Arctic. Changes are shown as rates during the observation period from approximately mid-1980s to present (the period varies between regions, and for N and E Asia the observation period was 1999 to present). The data were divided into seven first-order glaciated regions: (1) Alaska, (2) W Canada and W US, (3) Arctic Canada, (4) Greenland, (5) Scandinavia, (6) Arctic Russia, and (7) N and E Asia. Three of the first-order regions were divided into sub-regions illustrated on the Landsat images, indicating in total 12 sub-regions. Red circles show (GIC) shrinkage and blue circles advance (%). Circles with green margin show examples of GIC margin and area changes illustrated in Fig. 2. Background satellite images are from Landsat 5 TM.

The circumpolar Arctic region contains half of the estimated global glacier and ice cap surface area and two-thirds of its volume [5]. Even though GIC account for less than 1% of all the water on Earth that is bound in glacier ice, their increasing retreat and mass loss may dominate the glacial component of the global sea-level rise of the past century [6,7]. Analyses show that glacier and ice cap mass losses are currently raising the mean global sealevel by approximately 1 mm sea level equivalent (SLE) per year [7,8], which is broadly similar to the combined contributions from the Greenland Ice Sheet and the Antarctic Ice Sheet [8,9].

Throughout the approximately 25 years of satellite coverage, the Pan-Arctic GIC’s have faced widespread non-uniform shrinkage, where only 8%, 26 out of the 321 observed glaciers and ice caps, advanced in area [10] (Fig. 1). As an example, these non-uniform area changes are illustrated for 12 individual glaciers and ice caps (for both minor and major, Fig. 2), where 10 out of 12 showed retreat. On a sub-regional scale, half of the 12 regions showed retreat for all observed glaciers and ice caps, whereas 5% of the glaciers and ice caps advanced in Novaya Zemlya, 9% in SE Greenland, 10% in Kamchatka, 13% in W. Canada and the W. US, 37% in SW Greenland, and 42% on Bolshevik Island. The glacier and ice cap area changes on Bolshevik Island are not described in detail in the literature, therefore it is not yet possible to know whether the advancement is due more to positive net mass balance (climatic response) or to surging activities (climate-dynamic response). It is notable, however, that all the glaciers and ice caps on Bolshevik Island are facing north. Advancing glaciers and ice caps are, for all sub-regions, predominantly facing north (85%), and subject to dynamic response to changes in positive mass balance and climate. Surging activity is present and influences a real extent in Arctic Russia and Kamchatka. For example, for Novaya Zemlya 5% of the observed glaciers and ice caps advanced, where an identical percentage of glaciers and ice caps are known to surge [11], with 32 potential surge-types identified out of 692 glaciers and ice caps on the Novaya Zemlya archipelago.

For the compiled glacier and ice cap data set, the arithmetic mean relative area change was 21±1% from the mid-1980s to the present (here and following, the error term is stated as plus or minus one standard error). On the regional scale, Alaska faced an average shrinkage of

For more information contact Sebastian H. Mernild at smernild@gmail.com.

Funding Acknowledgments
LANL Director's Postdoctoral Fellowship

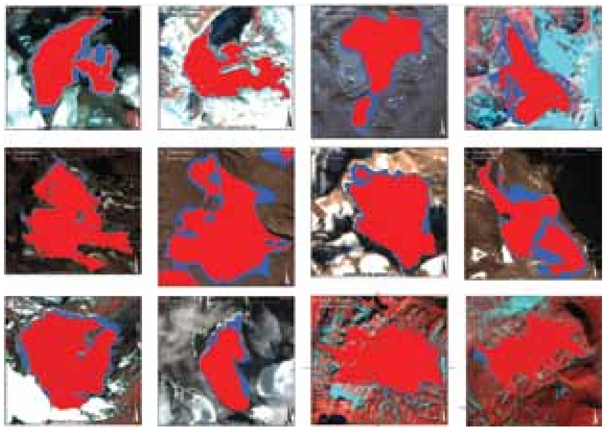

Fig. 2. Examples of satellite-derived margin location and area changes of 12 chosen glaciers and ice caps (for both minor and major glaciers and ice caps, one for each sub-region) for the period mid-1980s (blue) to present (red) estimated from Landsat images. The location of the GIC is shown in Fig. 1.

40±4%, Arctic Canada 35±4%, N and E Asia 23±3%, Scandinavia 21±2%, Greenland 20±2%, W. Canada and the W. US 12±3%, and Arctic Russia 12±2% (Fig. 1). For the Canadian Rocky Mountains, an area shrinkage of 15 - 25% (approximately 1950–2000) was computed [12,13], but a direct comparison to previous studies cannot be made due to the uneven observation periods. Overall, this shrinking trend follows the observed mean global glacier and ice cap mass balance trend towards negative balances (based on data from 144 observed glaciers and ice caps, Fig. 3). The mass balance from the most recent pentad (2006–2010) shows more moderate, although still large, losses.

Historically, the representation of shrinking and advancing glaciers and ice caps conditions has been either non-existent or limited to Pan-Arctic regions; however, satellite and aerial observations from SE Greenland go back to the 1930s [14]. Simultaneously mapping the shrinking and advancing behavior of Pan-Arctic glaciers and ice caps provides quantitative insight into the climate impacts on the cryosphere. For the last approximately 25 years shrinking of land-terminating glaciers and ice caps has been documented in high-latitude regions, covering a variation in loss rates from 40% in Alaska to 12% in Arctic Russia. To understand the glacier and ice cap response to climate change a new model study has just been initiated (Fig. 4) from which we will learn about the glacier and ice cap mass balance behavior across the Northern Hemisphere (north of 25° N) for the last four decades, clarifying the glacier and ice cap response in a warming climate and the temporal and spatial contribution of glacial mass loss to global sea-level rise.

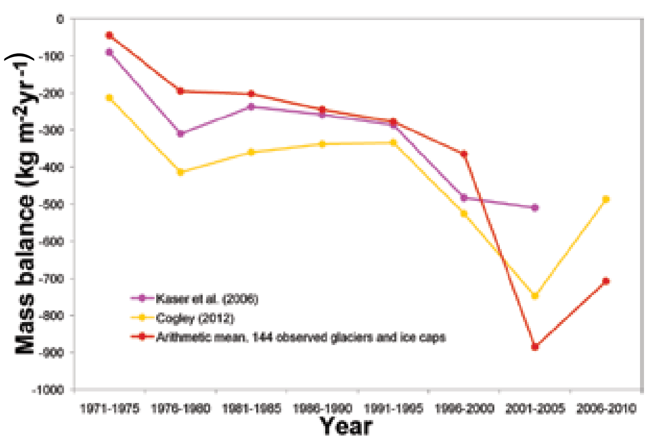

Fig. 3. Estimated global average glacier and ice cap mass balance at pentadal intervals (1971–2010) from published estimates and from the arithmetic mean of 144 glaciers and ice caps (red color).

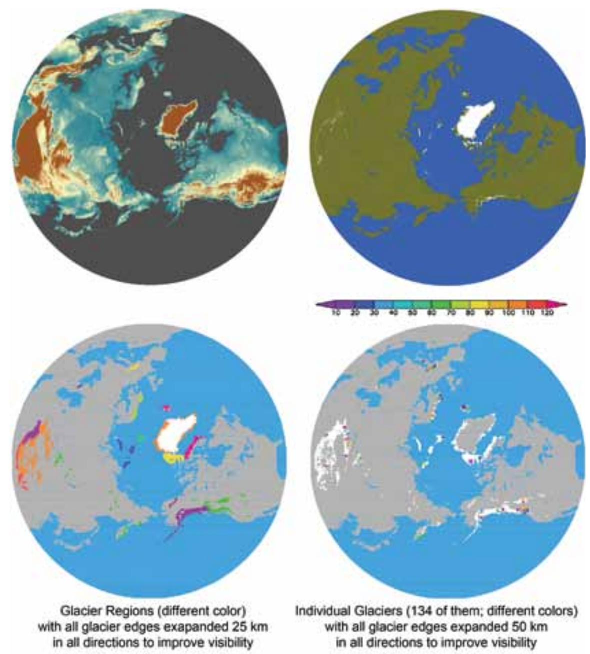

Fig. 4. Northern Hemisphere simulation domain: (upper left) topography (shaded from blue color [low elevations] to brown color [high elevations]); (upper right) surface characteristics (white color is glacier ice, green is grassland, forest, urban, etc., and blue is ocean and lakes); (lower left) different glacier and ice cap regions (following the IPCC AR5 regional division); and (lower right) locations of glaciers and ice caps where mass balance has been observed (within the simulation domain 134 glaciers and ice caps have been observed periodically; all individual glacier and ice caps are marked with a colored dot).

[1] Meier, M.F., *The Quaternary of the United States*, Eds H.E. Wright, D.G. Frey, Princeton University Press, New Jersey, 795 (1965).

[2] Kaser, G. et al., *Geophys Res Lett* **33**, 1 (2006).

[3] Hansen, J. et al., *Rev Geophys* **48**, RG4004 (2010).

[4] Mernild, S.H. et al., "Coastal Greenland Air Temperature Trends", *Int J Climatol*, in review (2012).

[5] Radić, V. and R.J. Hock, *Geophys Res* **115**, F01010 (2010).

[6] Leclercq, P.W. et al., *Surv Geophys* **32**, 519; doi10.1007/s10712-011-9121-7 (2011).

[7] Radić, V. and R. Hock, *Nature Geosci* **4**, 91 (2011).

[8] Cogley, J.G., *Ann Glaciol* **50**, 96 (2009).

[9] Meier, M.F. et al., *Science* **317**, 1064 (2007).

[10] Mernild, S.H. and J. K. Malmros, *The Cryosphere Discussion* **6**, 4417 (2012).

[11] Grant, K.L. et al., *J Glaciol* **55**(194), 960 (2009).

[12] Luckman, B.H. and T. Kavavagh, *Ambio* **29**, 371 (2000).

[13] DeBeer, C.M. and M.J. Sharp, *Ann Glaciol* **46**, 215 (2007).

[14] Bjork, A.A. et al., *Nature Geoscience* **5**; doi:10.1038/NGEO1481 (2012).